

APPENDIX V:

GRAIN-SIZE ANALYSIS

1. **DEFINITION.** Grain-size analysis is a process in which the proportion of material of each grain size present in a given soil (grain-size distribution) is determined. The grain-size distribution of coarse -grained soils is determined directly by sieve analysis, while that of fine-grained soils is determined indirectly by hydrometer analysis. The grain-size distribution of mixed soils is determined by combined sieve and hydrometer analyses. Detailed procedures for determining the grain-size distribution of soils by sieve, hydrometer, and combined analyses are given below.

2. **SIEVE ANALYSIS.** a. Description. A sieve analysis consists of passing a sample through a set of sieves and weighing the amount of material retained on each sieve. Sieves are constructed of wire screens with square openings of standard sizes. The sieve analysis is performed on material retained on a U. S. Standard No. 200 sieve. The sieve analysis, in itself, is applicable to soils containing small amounts of material passing the No. 200 sieve provided the grain-size distribution of that portion of the sample passing the No. 200 sieve is not of interest.

b. Apparatus. The apparatus should consist of the following:

(1) A series of U. S. standard sieves with openings ranging from 3 in. to 0.074 mm (No. 200), including a cover plate and bottom pan, conforming to ASTM Designation: E 11, Standard Specifications for Sieves for Testing Purposes.* The number and sizes of sieves used for testing a given soil will depend on the range of soil sizes in the material, and the intended use of the gradation curve.

(2) Sieve shaker, a mechanical unit which can produce on duplicate samples the same consistent results as those obtained by the circular and tapping motion used in hand sieving. Typical commercially available mechanical shakers are the Tyler "Ro-Tap" and the Combs and

* See page V-26 for U. S. Standard Sieve Sizes or numbers and sieve openings in inches and millimeters.

Syntron machines; there appears to be no significant differences in the results obtained among these machines.†

(3) Balances, sensitive to 0.1 g for samples weighing less than 500 g, and to 1.0 g for samples weighing over 500 g.

(4) Paintbrush, 1 in., or soft wire brush, for cleaning sieves.

(5) Sample splitter or riffle for dividing samples.

(6) Mortar and rubber-covered pestle, for breaking up aggregations of soil particles.

(7) Oven, similar to that described in Appendix I, WATER CONTENT - GENERAL.

c. Preparation of Sample.‡ The material to be treated is first air-dried, after which the aggregations present in the sample are thoroughly broken up with the fingers or with the mortar and pestle. A representative sample is then obtained by dividing, using the sample splitter or riffle. The size of the sample to be used will depend on the maximum particle size in the sample and the requirement that the sample be representative of the material to be tested. The sample should be limited in weight so that no sieve in the series will be overloaded. Overloading of a sieve will result in incomplete separation with errors in the test. The following tabulation will be used as a guide in obtaining a minimum-weight sample:

*

<u>Maximum Particle Size</u>	<u>Minimum Weight of Sample, g</u>
3 in.	64,000 g
2 in.	19,000 g
1-1/2 in.	8,000 g
1 in.	2,400 g
3/4 in.	1,000 g
1/2 in.	300 g
3/8 in.	150 g
No. 4	50 g

*

† U.S. Army Engineer Waterways Experiment Station, CE, Sieve Analyses of Granular Soils by Division Laboratories, Engineering Study 516 (Vicksburg, Miss., October 1963).

‡ Clay shale materials require special preparation. See paragraph 5.

If the sample contains more than about 10% of sizes larger than the No. 4 sieve, it is generally advisable to separate the material on the No. 4 sieve, retaining both fractions for independent sieve analysis as subsequently described. If the sample contains plastic fines which tend to form hard lumps or to coat the coarser particles during air-drying, the entire sample should be placed in a pan filled with water and allowed to soak until all the soil lumps or the coatings have disintegrated, before it is separated on the No. 4 sieve. The coarser fraction and the fraction passing the No. 4 sieve including the fines and water should be retained for independent sieve analysis as subsequently described.

d. Procedure. (1) Material predominantly finer than the No. 4 sieve. The procedure for samples predominantly finer than the No. 4 sieve consists of the following steps:

(a) Record all identifying information for the sample, such as project, boring number, or other pertinent data, on a data sheet (see Plate V-1 for suggested form).

(b) Oven-dry the sample at 110 ± 5 C, allow to cool, and weigh. If the sample weighs less than 500 g, weigh it to the nearest 0.1 g; if the sample weighs over 500 g, weigh to the nearest 1 g. Record the dry weight of the sample on the data sheet.

(c) If the sample consists of clean sands or gravels, proceed with step (f).[†] If the sample contains plastic fines which tend to form hard lumps or to coat the coarser particles during oven-drying, place the oven-dry sample in a pan filled with enough water to cover all the material and allow it to soak until all the soil lumps or coatings have disintegrated. The length of time required for soaking will vary from about 2 to 24 hr, depending in general on the amount and plasticity of the fines.

(d) Transfer the sample and water from the pan to a No. 200 sieve, or if the sample contains an appreciable amount of coarse

[†] If there is any doubt concerning the cleanness of a sand or gravel, i.e. whether or not the particles may be coated with fines, or if the test is performed to determine whether or not a material complies with specifications, then the sample should be treated as subsequently described in steps (c) through (e).

particles, to a combined set of No. 4 and No. 200 sieves. Care should be taken not to overload the No. 200 sieve; if necessary, transfer the sample in increments. Wash the sample thoroughly through the sieves, discarding the material passing the No. 200 sieve. Larger particles in the sample may be individually washed and removed from the sieves.

(e) Oven-dry the combined material retained on the No. 4 and the No. 200 sieves and, after the sample has cooled, weigh. Record on the data sheet in the "Weight Retained in grams" column the difference between the original oven-dry weight and the oven-dry weight after washing. Use the washed sample for the remainder of the analysis.

(f) Select a nest of sieves suitable to the soil being tested. The choice of sieves usually depends on experience and judgment, and the use for which the grain-size curve is intended. Select as the top

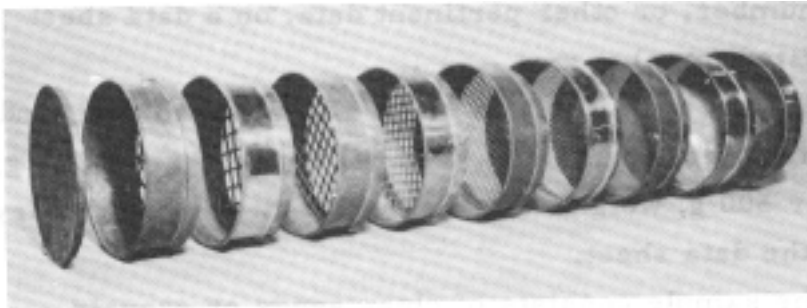


Figure 1. Arrangement of sieves for grain-size analysis

sieve, one with openings slightly larger than the diameter of the largest particle in the sample. Arrange the nest of sieves according to size as shown in Figure 1, with decreasing openings from top to bottom.

Attach the bottom pan to the bottom of the smallest sieve used. Place the sample on the top sieve of the nest as shown in Figure 2 and put the cover plate over the top sieve.

(g) Place the nest of sieves in the shaking machine as shown in Figure 3 and shake them for 10 min, more or less, or until additional shaking does not produce appreciable changes in the amounts of material on each sieve. If a shaking machine is not available, the nest of sieves may be shaken by hand. In the hand operation, shake the nest of

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sieves with a lateral and vertical motion, accompanied by jarring, to keep the material moving continuously over the surfaces of the sieves. Jarring is accomplished by occasionally dropping the nest lightly on several thicknesses of magazines. The nest should not be broken to rearrange particles or to manipulate them through a sieve by hand. Hand-shaking should be continued for at least 15 min.

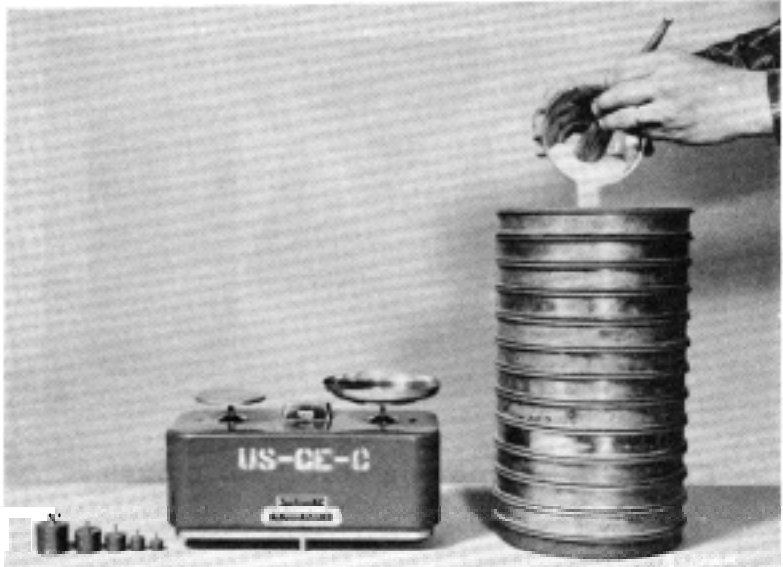


Figure 2. Placing soil on sieves

(h) Remove the nest of sieves from the mechanical shaker, if used. Beginning

with the top sieve, transfer the contents of the sieve to a piece of heavy paper approximately 1 ft square. Carefully invert the sieve on the paper and gently brush the bottom of the sieve, as shown in Figure 4, to remove all the sample.

Transfer the sample from the paper to the balance and weigh in accordance with requirements in

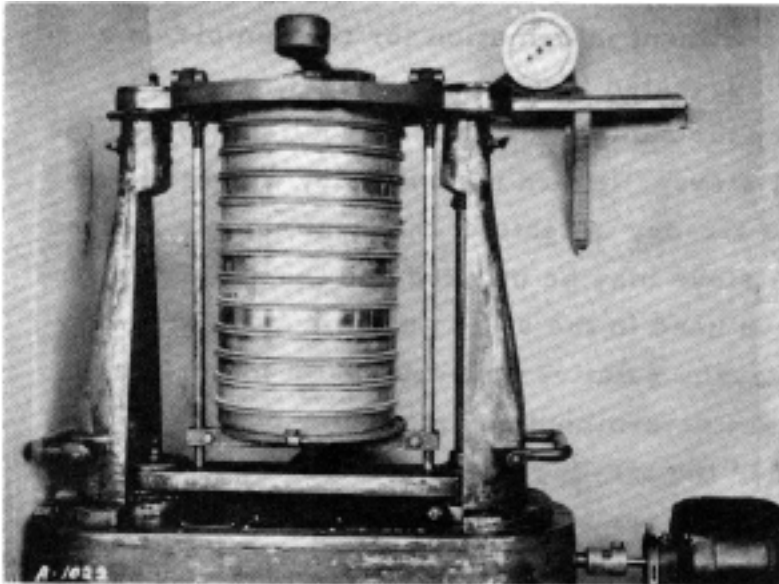


Figure 3. Nest of sieves placed in typical machine for shaking



Figure 4. Removing soil from sieves

step (b). Care should be exercised that no loss of material occurs during the transfer. Coarser fractions may be transferred more readily from the sieves directly onto the balance pan. Record the weight of material retained on each sieve on the data sheet.

(i) Repeat step (h) for each sieve. The sum of the weights retained on each sieve and pan should equal the initial total weight of the sample within 1 percent. If the difference is greater than 1 percent, the sieving should be repeated.

(2) Material split on No. 4 sieve. The procedure for samples which have been split on the No. 4 sieve consists of the following steps:

(a) Record pertinent information for the sample on a data sheet (see Plate V-i for suggested form).

(b) Oven-dry the sample, allow it to cool, and weigh the fraction retained on the No. 4 sieve. Record the oven-dry weight on the data sheet. Alternatively, the air-dry weights of the total sample and the fraction retained on the No. 4 sieve may be utilized and the air-dry material retained on the No. 4 sieve used in the sieve analysis as in step (c) below. In the latter procedure, the relative percentages of materials greater than the No. 4 sieve are determined on an air-dry basis. This method is satisfactory provided the air-dry water contents of the plus and minus No. 4 portions of the sample are approximately equal.

(c) Proceed as in paragraphs 2d(1)(f) through 2d(1)(i). In general, it is advisable to use large sieves and a Ty-Lab or Gilson shaker for the coarse fraction.

(d) If the sample has not been washed during the preliminary treatment, process the material passing the No. 4 sieve according to paragraphs 2d(1)(b) through 2d(1)(i). If the material has been washed as part of the preliminary treatment, proceed with paragraphs 2d(1)(d) through 2d(1)(i), except that the material passing the No. 200 sieve in paragraph 2d(1)(d) should be oven-dried and weighed. This weight is added to the oven-dry weight of the plus No. 200 material to obtain the total weight of sample.

e. Computations. The percentage of material by weight retained on the various sieves is computed as follows:

$$\text{Percent retained} = \frac{\text{weight in g retained on a sieve}}{\text{total weight in g of oven-dry sample}} \times 100$$

If the sample has been split on the No. 4 sieve during preliminary treatment and the air-dried coarser fraction sieved independently, the percent retained for the coarser fraction is computed as follows:

$$\text{Percent retained} = \frac{\text{air-dry weight in g retained on a sieve}}{\text{air-dry weight in g of total sample}} \times 100$$

Similarly, for the finer fraction when oven-dry weights are used:

$$\text{Percent retained} = \frac{\text{weight in g retained on a sieve}}{\text{oven-dry weight in g of sample passing No. 4 sieve}} \times \text{percent passing No. 4}$$

where the percentage passing No. 4 sieve is computed on an air-dry basis. The values of percent retained based on the above formulas refer to the total weight of sample. Computation of a partial percent retained as indicated in Plate V-i is necessary only when the sample is initially separated on the No. 200 sieve for purposes of a combined analysis, as subsequently described. The cumulative percent finer by weight than an individual sieve size (percent finer) is calculated by subtracting the percent retained

on the individual sieve from the cumulative percent finer than the next larger sieve.

f. Presentation of Results. The results of the sieve analysis are presented in the form of a grain-size distribution curve on a semi-logarithmic chart as shown in Plate V-2. The grain-size distribution curve is obtained by plotting particle diameter (sieve opening) on the abscissa (logarithmic scale) and the percent finer by weight on the ordinate (arithmetic scale).

3. **HYDROMETER ANALYSIS.** a. Description. The hydrometer method of analysis is based on Stokes' law, which relates the terminal velocity of a sphere falling freely through a fluid to the diameter. The relation is expressed according to the equation:

$$v = \frac{\gamma_s - \gamma_f}{1800 \eta} D^2$$

where v = terminal velocity of sphere, cm per sec

γ_s = density of sphere, g per cm³

γ_f = density of fluid, g per cm³

η = viscosity of fluid, g-sec per cm²

D = diameter of sphere, mm

It is assumed that Stokes' law can be applied to a mass of dispersed soil particles of various shapes and sizes. The hydrometer is used to determine the percentage of dispersed soil particles remaining in suspension at a given time. The maximum grain size equivalent to a spherical particle is computed for each hydrometer reading using Stokes' law. The hydrometer analysis is applicable to soils passing the No. 10 sieve for routine classification purposes; when greater accuracy is required (such as in the study of frost-susceptible soils), the hydrometer analysis should be performed on only the fraction passing the No. 200 sieve (see paragraph COMBINED ANALYSIS).

b. Apparatus. The apparatus should consist of the following:

(1) Hydrometer, calibrated at 20/20 C (68/68 F), graduated in specific gravity or grams per liter with a range of 0.995 to 1.040 and 0 to 50, respectively. The accuracy of the specific gravity hydrometer shall be 0.001 and of the gram-per-liter hydrometer, ± 1 .

(2) Dispersion apparatus, either of two types may be used:

(a) A mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10,000 rpm without load. The shaft shall be equipped with a replaceable stirring paddle of metal, plastic, or hard rubber. Details of a typical paddle are shown in Figure 5. A special dispersion cup conforming to either of the designs shown in Figure 5 shall be provided to hold the sample while it is being dispersed.

(b) An air dispersion device such as the air-jet dispersion tube device

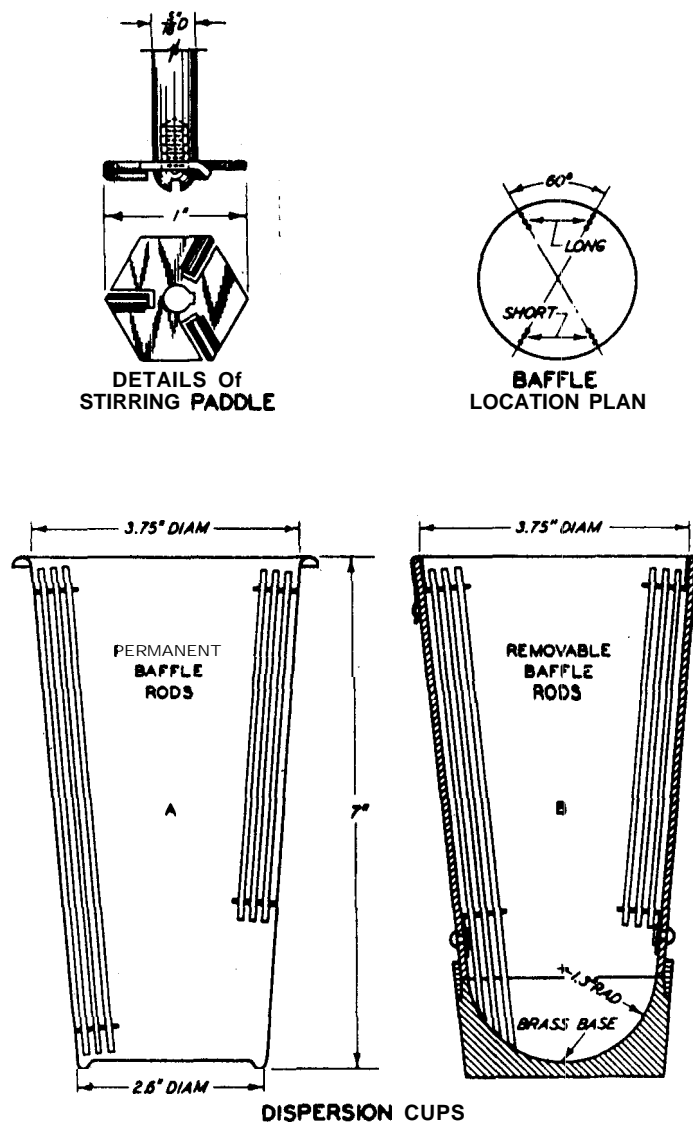


Figure 5. Detail of stirring paddle and dispersion cups

developed at Iowa State College.†

(3) Sedimentation cylinder, of glass, essentially 18 in. high and 2-1/2 in. in diameter and marked for a volume of 1000 ml.

(4) Centigrade thermometer, range 0 to 50 C, accurate to 0.5 c.

(5) Timing device, a watch or clock with a second hand.

(6) Balance, sensitive to 0.1 g.

(7) Oven (see Appendix I, WATER CONTENT - GENERAL).

c. Hydrometer Calibration. The hydrometer shall be calibrated‡ to determine its true depth in terms of the hydrometer reading (see Fig. 6) in the following steps:

(1) Determine the volume of the hydrometer bulb, V_R . This may be determined in either of two ways:

(a) By measuring the volume of water displaced. Fill a 1000-cc graduate with water to approximately 700 cc. The water should be at about 20 C. Observe and record the reading of the water level. Insert the hydrometer and again observe and record the reading. The difference in these two readings equals the volume of the bulb plus the part of the stem that is submerged. The error due to inclusion of this latter quantity is so small that it may be neglected for practical purposes.

(b) By determining the volume from the weight of the hydrometer. Weigh the hydrometer to 0.01 g on the laboratory balance. Since the specific gravity of a hydrometer is, about unity, the weight in grams may be recorded as the volume in cubic centimeters. This volume includes the volume of the bulb plus the volume of the stem. The error

† T. Y. Chu and D. T. Davidson, "Simplified air-jet dispersion apparatus. for mechanical analysis of soils," Proceedings, Highway Research Board, vol. 32 (1953), pp. 541-547.

‡ ASTM hydrometers 151 H or 152 H (ASTM Designation: E 100) have a uniform size; therefore, only a single calibration is required, which can be applied to all ASTM hydrometers of this type.

due to inclusion of the stem volume is negligible.

(2) Determine the area, A , of the graduate in which the hydrometer is to be used by measuring the distance between two graduations. The area, A , is equal to the volume included between the graduations divided by the measured distance.

(3) Measure and record the distances from the lowest calibration mark on the stem of the hydrometer to each of the other major calibration marks, R .

(4) Measure and record the distance from the neck of the bulb to the lowest calibration mark. The distance, H_1 , corresponding to a reading, R , equals the sum of the two distances measured in steps (3) and (4).

(5) Measure the distance from the neck to the tip of the bulb. Record this as h , the height of the bulb. The distance, $h/2$, locates the center of volume of a symmetrical bulb. If a nonsymmetrical bulb is used, the center of volume can be determined with sufficient accuracy by projecting the shape of the bulb on a sheet of paper and locating the center of gravity of this projected area.

(6) Compute the true distances, H_R , corresponding to each

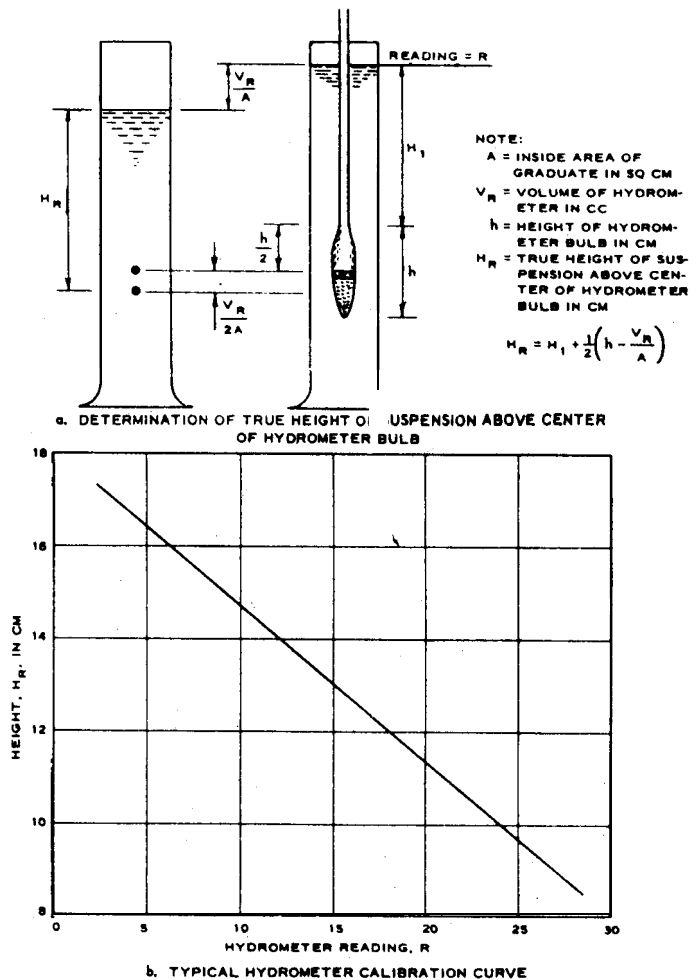


Figure 6. Hydrometer calibration

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of the major calibration marks, R , from the formula:

$$H_R = H_1 + \frac{1}{2} \left(h - \frac{V_R}{A} \right)$$

(7) Plot the curve expressing the relation between H_R and R as shown in Figure 6. The relation is essentially a straight line for hydrometers having a streamlined shape.

d. Meniscus Correction. Hydrometers are calibrated to read correctly at the surface of the liquid. Soil suspensions are not transparent and a reading at the surface is not possible; therefore, the hydrometer reading must be made at the upper rim of the meniscus. The meniscus correction, C_m , which is a constant for a given hydrometer, is determined by immersing the hydrometer in distilled or demineralized water and observing the height to which the meniscus rises on the stem above the water surface. For most hydrometers it will be found that C_m is equal to approximately 0.5, and this value can be assumed for routine testing.

e. Preparation of Sample. The approximate size of sample to be used for the hydrometer analysis varies according to the type of soil being tested, as shown in the tabulation below:

<u>Soil Type</u>	<u>Dry Weight, g</u>
Fat clays	30
Lean clays and silty soils	50
<u>Sandy soils</u>	<u>75†</u>

† Up to 150 g of sandy soil can be used for the hydrometer analysis provided no more than 50 g of the sample is finer than the No. 200 sieve.

The exact dry weight of the sample in suspension may be determined either before or after the test. However, oven-drying some clays before the test may cause permanent changes in the apparent grain sizes. Samples of such soils should, if possible, be preserved at the natural

water content and tested without first being oven-dried, the dry weight either being obtained after the hydrometer analysis or computed according to the formula:

$$\text{Dry weight of specimen} = \frac{\text{weight of wet soil}}{1 + \frac{\text{water content}}{100}}$$

$$W_s = \frac{W}{1 + 0.01 w}$$

w having been determined on an untested portion of the sample.

Furthermore, if samples are dried and weighed before the test, any loss of material during the test will affect the results.

f. Dispersing Agent. Very fine soil grains in a suspension normally will tend to flocculate, i.e. to adhere with sufficient force that they settle together. Consequently, a dispersing agent to prevent flocculation of the soil grains during the test should be added to all samples. The following dispersing agents, listed in approximate order of effectiveness, have been found to be satisfactory for most types of soils.†

Dispersing Agents	Stock Solution		Manufacturer
	Concen- tration	g per liter	
1 Sodium tripolyphosphate	0.4 N	29	Blockson Chem. Co., Joliet, Ill.
2 Sodium polyphosphate	0.4 N	36	Blockson Chem. Co., Joliet, Ill.
3 Sodium tetraphosphate (trade name "Quadrafos")	0.4 N	31	Rumford Chem. Works, Rumford, R. I.
* 4 Sodium Hexametaphosphate (sometimes called sodium metaphosphate) adjusted to pH8-9 with Na ₂ CO ₃	0.4 N	41	Most laboratory chemical supply c os.

The chemical product Calgon available in grocery stores shall not be used as a dispersing agent as it no longer contains sodium hexametaphosphate. Sodium silicate shall not be used as a dispersing agent since it gives unsatisfactory dispersion while at the same time permitting flocculation to a

† A. M. Wintermyer and E. B. Kinter, "A study of dispersing agents for particle-size analysis of soils," Public Roads, vol. 28, No. 3 (August 1954), pp 55-62.

point where it is not apparent to visual examination. Phosphate solutions are somewhat unstable and therefore should not be stored for extended periods of time. In most instances, 15 ml of a dispersing agent solution is adequate. However, should flocculation tend to continue, a second or third addition of 15 ml of solution may be added.

The addition of a dispersing agent to the soil suspension results in an increase in density of the liquid and necessitates a correction to the observed hydrometer reading. The correction factor, C_d , is determined by adding to a 1000-ml graduate partially filled with distilled or demineralized water the amount of dispersing agent to be used for the particular test, adding additional distilled water to the 1000-ml mark, then inserting a hydrometer and observing the reading. The correction factor, C_d , is equal to the difference between this reading and the hydrometer reading in pure distilled or demineralized water.

The addition of a dispersing agent also increases the weight of solids in the suspension. If the oven-dry weight of soil used for the hydrometer analysis is obtained at the end of the test, this weight must be corrected by subtracting the dry weight of the dispersing agent used.

g. Procedure. The procedure shall consist of the following steps:

(1) Record all identifying information for the sample, such as project, boring number, or other pertinent data, on a data sheet (see Plate V-3 for suggested form).

(2) Determine the dispersing agent correction, C_d , and the meniscus correction, C_m , unless they have been previously established. Record this information on the data sheet.

(3) Determine or estimate the specific gravity of solids and record on the data sheet.

(4) If the oven-dry weight is to be obtained at the start of the test, oven-dry the sample, allow to cool, and weigh to nearest 0.1 g. Record the dry weight on the data sheet. Place the sample in a numbered dish and add distilled or demineralized water until the sample is submerged. Add

the dispersing agent at this time. Allow the sample to soak overnight or until all soil lumps have disintegrated. Highly organic soils require special treatment, and it may be necessary to oxidize the organic matter in order to perform a hydrometer analysis on these soils. Oxidation is accomplished by mixing the sample with a solution of 30 percent hydrogen peroxide; this solution will oxidize all the organic matter. If only small amounts of organic matter are present, treatment with hydrogen peroxide may be omitted.

(5) Transfer the soil-water slurry from the dish to a dispersion cup (Fig. 5), washing† any residue from the dish with distilled or demineralized water. Add distilled water to the dispersion cup, if necessary, until the water surface is 2 or 3 in. below the top of the cup; if the cup contains too much water, it will splash out while mixing. Place the cup in the dispersing machine and disperse the suspension for 1 to 10 min. The lower the plasticity of the soil the shorter the time required to disperse it in the cup.‡

(6) Transfer the suspension into a 1000-ml sedimentation cylinder and add distilled or demineralized water until the volume of the suspension equals 1000 ml. The suspension should be brought to the temperature expected to prevail during the test.

(7) One minute before starting the test, take the graduate in one hand and, using the palm of the other hand or a suitable rubber cap as a stopper, shake the suspension vigorously for a few seconds in order to transfer the sediment on the bottom of the graduate into a uniform suspension. Continue the agitation for the remainder of the minute by turning the cylinder upside down and back. Sometimes it is necessary to loosen the

† A large syringe or wash-water bottle is a convenient device for handling the water in the washing operation.

‡ Air dispersion may be used in place of mechanical dispersion. A dispersion time of 10 min is recommended, using an air pressure of 25 psi for clays and silts and 10 psi for sands. Several comparative tests indicate that the air dispersion apparatus gives a higher degree of dispersion of clayey soils while causing less degradation of sands than the mechanical stirring apparatus. See: Chu and Davidson, op. cit., and U. S. Bureau of Reclamation, Comparison of Dispersion Methods for Soil Gradation Analysis, Earth Laboratory Report No. EM-618 (Denver, Colo., May 1961).

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sediment at the bottom of the cylinder by means of a glass rod before shaking. Alternatively, the suspension may be agitated by means of a hand agitator for one minute prior to testing. A schematic drawing of a hand agitator is shown in Figure 7. A uniform distribution of the soil particles in the suspension is accomplished by moving the hand agitator up and down through the suspension for one minute. This process also prevents the accumulation of sediment on the base and sides of the graduate.

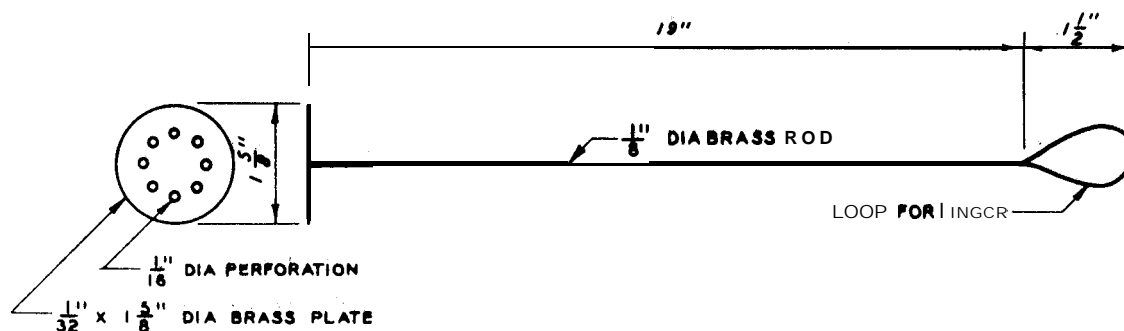


Figure 7. Hand agitator for hydrometer cylinder

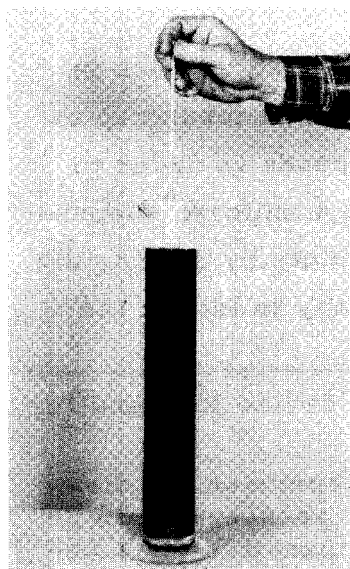


Figure 8. Immersing hydrometer in suspension prior to making observation

(8) At the end of 1 min, set the cylinder on a table. If foam is present, remove it from the top of the suspension by lightly touching it with a piece of soap. Slowly immerse the hydrometer in the liquid 20 to 25 sec before each reading, as shown in Figure 8. Care should be exercised when inserting and removing the hydrometer to prevent disturbance of the suspension.

(9) Observe and record the hydrometer readings on the data sheet after 1 and 2 min have elapsed from the time the cylinder is placed on the table. As soon as the 2-min reading has been taken, carefully remove the hydrometer from the suspension and place it in a graduate of clean water. (If a hydrometer is left in a soil suspension for any length of time, material will

settle on or adhere to the hydrometer bulb and this will cause a significant error in the reading.) Again insert the hydrometer in the suspension and record readings after elapsed times of 4, 15, 30, 60, 120,† 240, and 1440 min, removing the hydrometer from the suspension after each reading and placing it in a graduate of clean water. Make all hydrometer readings at the top of the meniscus. For hydrometers graduated to read in specific gravity of the suspension, read only the last two figures and estimate the third. Record the indicated specific gravity, minus 1, multiplied by 1000 (example: the reading 1.0225 should be recorded as 22.5). For hydrometers graduated to read grams per liter of suspension, record the actual reading.

(10) At the end of 2 min and after each subsequent hydrometer reading, place a thermometer in the suspension and record the temperature reading on the data sheet. The temperature shall be recorded to ± 0.5 C. Temperature changes of the soil suspension during the test will affect the test results. Variations in temperature should be minimized by keeping the suspension away from heat sources such as radiators, sunlight, or open windows. A constant-temperature bath provides a convenient means of controlling temperature effects.

(11) If the dry weight of the sample is to be obtained at the end of the test, carefully wash all the suspension into an evaporating dish. Oven-dry the material, allow to cool, and determine the sample weight. Subtract the dry weight of dispersing agent used from this weight to obtain the oven-dry weight of soil.

h. Computations. (1) Corrected hydrometer reading. Compute the corrected hydrometer readings, R , for use in computing particle diameter by adding the meniscus correction, C_m , to the actual hydrometer readings, R' . Record the corrected reading, R , on the data sheet.

(2) Computation of particle diameter. Calculate the particle

† A final reading after 120 min is sufficient for most soils when hydrometer analysis is used for classification purposes.

diameter corresponding to a given hydrometer reading on the basis of Stokes' equation, using the nomograph shown in Figure 9. The R-scale corresponding to the distances H_R is prepared using the hydrometer calibration curves as shown in Figure 6. The R-scale shall be designed for the particular hydrometer used in the test. A key showing the steps to follow in computing D for various values of R is shown on the chart. Record the particle diameters, D, on the data sheet.

(3) Percent finer. To compute the percent of particle diameters finer than that corresponding to a given hydrometer reading, subtract the dispersing agent correction, C_d , from the corrected hydrometer reading, R. A temperature correction factor, m, must also be added algebraically to each of the readings. This factor can be either positive or negative depending on the temperature of the suspension at the time of each reading. Obtain the temperature correction factors from Table V-i and record them on the data sheet. Record the values of $R - C_d + m$ on the data sheet. The $R - C_d + m$ values are used to compute percent finer according to the following formulas:

Hydrometer calibrated in specific gravity:

$$\text{Percent finer by weight} = \frac{G_s}{G_s - 1} \times \frac{100}{W_s} (R - C_d + m)$$

Hydrometer calibrated in grams per liter:

$$\text{Percent finer by weight} = \frac{100}{W_s} (R - C_d + m)$$

where G_s = specific gravity of solids

$W_s = W_o$ = oven-dry weight in g of soil used for hydrometer analysis

$R - C_d + m$ = corrected hydrometer reading minus dispersing agent correction plus, algebraically, temperature correction

Calculations for routine work can be greatly facilitated by using charts, tables, and other simplifying aids based on a given oven-dry weight of the sample and average specific gravity values for the major soil groups.

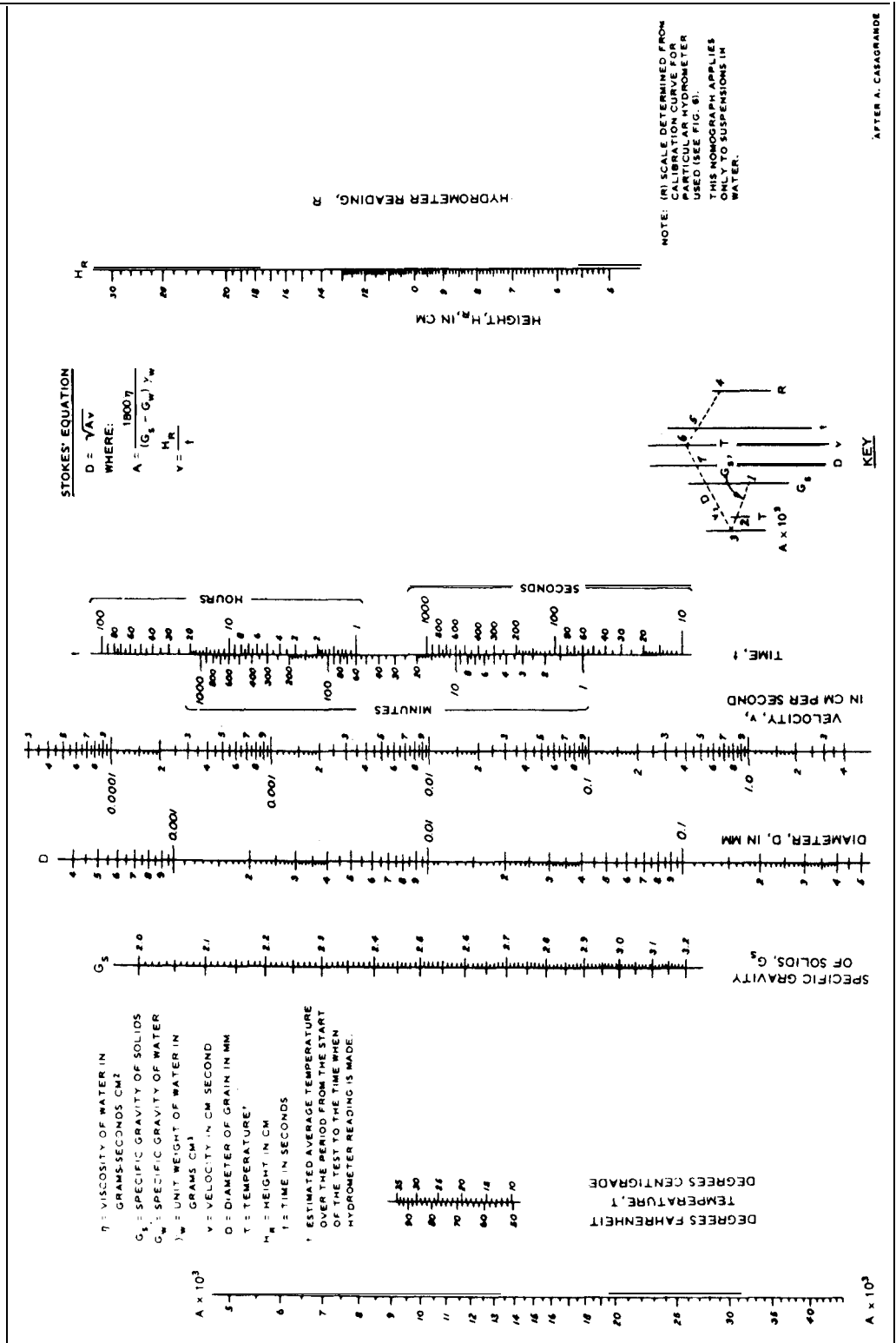


Figure 9. Nomographic chart

Table V-1

Temperature Correction Factor, m, forUse in Computing Percent Finer

<u>Degrees</u> <u>C</u>	<u>Degrees</u> <u>F</u>	<u>Correction</u>	<u>Degrees</u> <u>C</u>	<u>Degrees</u> <u>F</u>	<u>Correction</u>
14.0	57.2	-0.9	24.0	75.2	+0.8
14.5	58.1	-0.8	24.5	76.1	+0.9
15.0	59.0	-0.8	25.0	77.0	+1.0
15.5	59.9	-0.7	25.5	77.9	+1.1
16.0	60.8	-0.6	26.0	78.8	+1.3
16.5	61.7	-0.6	26.5	79.7	+1.4
17.0	62.6	-0.5	27.0	80.6	+1.5
17.5	63.5	-0.4	27.5	81.5	+1.6
18.0	64.4	-0.4	28.0	82.4	+1.8
18.5	65.3	-0.3	28.5	83.3	+1.9
19.0	66.2	-0.2	29.0	84.2	+2.1
19.5	67.1	-0.1	29.5	85.1	+2.2
20.0	68.0	0.0	30.0	86.0	+2.3
20.5	68.9	+0.1	30.5	86.9	+2.5
21.0	69.8	+0.2	31.0	87.8	+2.6
21.5	70.7	+0.3	31.5	88.7	+2.8
22.0	71.6	+0.4	32.0	89.6	+2.9
22.5	72.5	+0.5	32.5	90.5	+3.0
23.0	73.4	+0.6	33.0	91.4	+3.2
23.5	74.3	+0.7	33.5	92.3	+3.3
			34.0	93.2	+3.5

1. Presentation of Results. The data obtained from the hydrometer analysis are presented in the form of a grain-size distribution curve on a semilogarithmic chart, as shown in Plate V-2.

4. COMBINED ANALYSIS. a. Description. A combined analysis is necessary for soils containing material finer than the U. S. Standard No. 200 sieve when the grain-size distribution of the material passing the No. 200 sieve is of interest. A sieve analysis is performed on the material retained on the No. 200 sieve, and a hydrometer test is performed on the material passing the No. 200 sieve.

b. Apparatus. The apparatus for the combined analysis is the same as that used for both the hydrometer and sieve analyses.

c. Preparation of Sample. A representative sample for the combined analysis is selected and prepared in the manner described in paragraph 2c. The total amount of sample should be sufficient to yield required amounts of material for both the sieve and hydrometer analyses. A visual inspection of the sample will usually suffice to indicate the need for intermediate steps such as large screen processing for the plus No. 4 fraction, washing, etc. Samples of soils having fines with little or no plasticity are oven-dried, weighed, and then separated on the No. 200 sieve. The plus and minus No. 200 sieve fractions are preserved for the sieve and hydrometer analyses, respectively.

Soils containing plastic fines may also be oven-dried initially. However, if the sample contains plastic fines which tend to form hard lumps or to coat the coarser particles during oven-drying, the sample is placed in a pan filled with enough water to cover all the material and allowed to soak until all the lumps *or* coatings have been reduced to individual particles. The length of time required for soaking will vary from 2 to 24 hr, depending in general on the amount and plasticity of the fines. The water and soil mixture is then washed over a No. 200 sieve (and No. 4 sieve, if necessary). The coarser fractions are preserved for a sieve analysis, and the soil and water passing the No. 200 sieve are preserved

for a hydrometer analysis. Excess water with the fines is removed by evaporation, filtration, or wicking. If the grain size of the plastic fines would be altered by oven-drying. The oven-dry weight of the fines is determined after the hydrometer test.

In routine testing when all soil particles are finer than the No. 10 sieve size, the hydrometer test may be performed on a total sample of known dry weight; the sample is then washed through the No. 200 sieve, and finally the sieve analysis is performed on the oven-dried fraction retained on the No. 200 sieve.

d. Procedure. The procedure shall consist of the following steps:

* (1) Record identifying information for the sample on both the sieve and hydrometer analysis data sheets (see Plate V-1). *

(2) Perform a sieve analysis on a representative portion of the sample retained on the No. 200 sieve, using the procedures described in paragraphs 2d(1) and 2d(2).

(3) Perform a hydrometer analysis on a portion (see paragraph 3e for approximate weight) of the sample passing the No. 200 sieve, using the procedure described in paragraph 3g.

e. Computations. The computations consist of the following steps:

(1) Compute the percentage retained on the No. 200 sieve for the total sample used in the combined analysis as follows:

$$\text{Percent retained on No. 200 sieve} = \frac{W_1}{W_s} \times 100$$

where W_1 = dry weight of sample retained on No. 200 sieve

W_s = total dry weight of sample used for combined analysis

(2) Compute the data from the sieve analysis in the same manner as outlined in paragraphs 2d(1) and 2d(2), except that the percent retained for each sieve shall be based only on that portion of the total material used for the sieve analysis. As the amount of material used in the sieve analysis may be less than W_1 , it will be necessary to compute

a partial percent retained as follows:

$$\text{Partial percent retained} = \frac{\text{weight in g retained on a sieve}}{\text{total weight in g of oven-dry sample used for sieve analysis}} \times 100$$

The total percent retained is computed as follows:

$$\text{Total percent retained} = \text{partial percent retained} \times \frac{W_1}{W_s}$$

The total percent finer is computed as follows:

$$\text{Total percent finer} = 100 - \text{total percent retained}$$

(3) Compute the data from the hydrometer analysis in the same manner as outlined in paragraphs 3h(1) through 3h(3), except that the results shall be shown in terms of a partial percent finer. As in the sieve analysis, the amount of material used for the hydrometer analysis may be less than $W_s - W_1$, therefore a partial percent finer is computed as follows:

Hydrometer calibrated in specific gravity:

$$\text{Partial percent finer} = \frac{G_s}{G_s - 1} \times \frac{100}{W_o} (R - C_d + m)$$

Hydrometer calibrated in grams per liter:

$$\text{Partial percent finer} = \frac{100}{W_o} (R - C_d + m)$$

where W_o = oven-dry weight in g of soil used for hydrometer analysis

Other terms were defined previously.

The total percent finer is computed as follows:

$$\text{Total percent finer} = \text{partial percent finer} \times \frac{W_s - W_1}{W_s}$$

f. Presentation of Results. The results of the combined analysis

in terms of particle diameter and total percent finer by weight are presented in the form of grain-size distribution curves on a semilogarithmic chart as shown in Plate V-2. The curves obtained from the sieve and hydrometer analyses are joined by constructing a smooth curve between them.

5. **PROCEDURES FOR PREPARING CLAY SHALE MATERIAL.** The procedures for preparing clay shale material shall be the same as those described in paragraph 4, page III- 14, Appendix III, LIQUID AND PLASTIC LIMITS. Material for a particle-size distribution test should be removed from a processed batch and the test performed in accordance with the procedures described in this appendix. However, the material should not be oven-dried before testing, and the hydrometer analysis should be of duration sufficient to determine the percent finer than 2- μ size.

6. **POSSIBLE ERRORS.** Following are possible errors that would cause inaccurate determinations of grain-size distribution:

a. Sieve Analysis. (1) Aggregations of particles not thoroughly broken. If the material contains plastic fines, the sample should be slaked before sieving.

(2) Overloading sieves. This is the most common and most serious error associated with the sieve analysis and will tend to indicate that a material is coarser than it actually is. Large samples may have to be sieved in several portions, and the portions retained on each sieve recombined afterwards for weighing.

(3) Sieves shaken for too short a period or with inadequate horizontal or jarring motions. The sieves must be shaken so that each particle is exposed to the sieve openings with various orientations and has every opportunity to fall through.

(4) Broken or deformed sieve screens. Sieves must be frequently inspected to ensure they contain no openings larger than the standard.

(5) Loss of material when removing soil from each sieve.

b. Hydrometer Analysis. (1) Soil oven-dried before test. Except

for inorganic soils of low dry strength, oven-drying may cause permanent changes in the particle sizes.

(2) Unsatisfactory type or quantity of dispersing agent.

Whenever new or unusual soils are tested, trials may be necessary to determine the type and quantity of chemical which gives the most effective dispersion and deflocculation.

(3) Incomplete dispersion of soil into suspension.

(4) Insufficient shaking or agitating of suspension in cylinder at start of test.

(5) Too much soil in suspension. The results of the hydrometer analysis will be affected if the size of the sample exceeds the recommendations given in paragraph 3e.

(6) Disturbance of suspension while inserting or removing hydrometer. Such disturbance is most likely to result when the hydrometer is withdrawn too rapidly after a reading.

(7) Stem of hydrometer not clean. Dirt or grease on the stem may prevent full development of the meniscus.

(8) Nonsymmetrical heating of suspension,

(9) Excessive variation in temperature of suspension during test.

(10) Loss of material after test. If the oven-dry weight of the soil is obtained after the test, all of the suspension must be washed carefully from the cylinder.

c. Combined Analysis. (1) Insufficient washing of material over the No. 200 sieve. The dispersing agent should be added to the water in which the sample is soaked and the soil-water mixture should be frequently manipulated to aid the separation of particles; coarser particles may be removed from the mixture and washed free of fines by hand to reduce the quantity of material to be washed on the sieve. While the additional water used for washing should be held to a minimum, enough must be added to insure adequate removal of the fines.

(2) Loss of suspension passing the No. 200 sieve.

SIEVE AND HYDROMETER ANALYSIS

(EM 1110-2-1906)

PART I - SIEVE ANALYSIS

DATE

PROJECT

BORING NO.

SAMPLING NO.

TOTAL WEIGHT IN GRAMS OF SAMPLE, W_s =

WEIGHT IN GRAMS OF MATERIAL $>$ NO. 4 SIEVE =

STEVE OPENINGS		U.S. STANDARD SIEVE SIZE OR NUMBER	WEIGHT RETAINED IN GRAMS	PERCENT RETAINED		PERCENT FINER BY WEIGHT
INCHES	MILLIMETERS			PARTIAL	TOTAL	
3.00		3-in.				
2.00		2-in.				
1.50		1-1/2-in.				
1.00	25.4	1-in.				
0.750	19.1	3/4-in.				
0.500	12.7	1/2-in.				
0.375	9.52	3/8-in.				
0.250	6.35	No. 3				
0.187	4.76	No. 4				
		Pan				
0.132	3.36	No. 6				
0.094	2.38	No. 8				
0.079	2.00	No. 10				
0.047	1.19	No. 16				
0.033	0.84	No. 20				
0.023	0.59	No. 30				
0.0165	0.42	No. 40				
0.0117	0.297	No. 50				
0.0083	0.210	No. 70				
0.0059	0.149	No. 100				
0.0041	0.105	No. 140				
0.0029	0.074	No. 200				
		Pan				
TOTAL WEIGHT IN GRAMS						

Partial percent retained = $\frac{\text{wt in grams retained on a sieve}}{\text{wt in grams of sample used for a given series of sieves}} \times 100$

Total percent retained = $\frac{\text{wt in grams retained on a sieve}}{\text{total wt in grams of oven-dry sample}} \times 100$

For an individual sieve, the percent finer by weight = percent finer than next larger sieve - percent retained on individual sieve

REMARKS

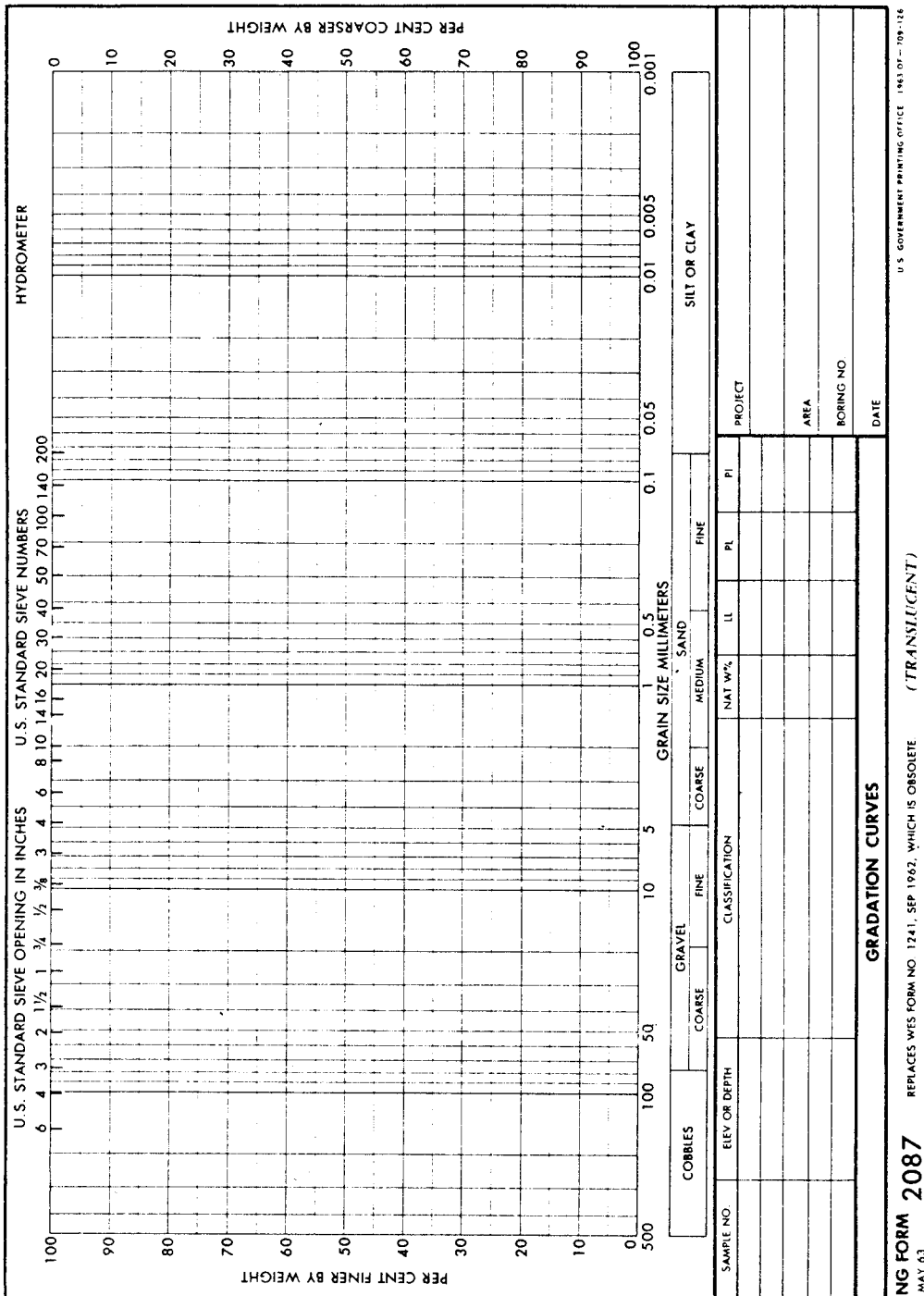
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REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE.

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MAY 63

PLATE V-2

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